SignalEx: Relating the Channel to Modem Performance

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LONG-TERM GOALS

To understand how the ocean-channel affects acoustic communications, thereby develop tools to predict system performance, and produce a channel-adaptive signaling scheme for optimal communications.

OBJECTIVES/BACKGROUND

The rapid international development of the mobile phone business has led to significant advances in communications engineering. However, the experience base for underwater acoustic communications is much more limited. Meanwhile, the ocean channel has unique characteristics, so that one cannot assume radio modulation schemes are suitable for acoustic communications in the ocean (and vice versa). Users of acoustic modems in the ocean often find that a system that worked well in one area performs badly or not at all in a new site. In general, the acomms community does not have a capability to reliably predict network performance in new sites. The objective of the SignalEx tests is address this problem by developing insights about how different environmental conditions affect different signaling schemes.

APPROACH

One of the key problems in comparing modem performance is to separate issues that are associated with the hardware from those inherent to the modulation scheme. Perhaps the most obvious example is transmit power: obviously the modem with the higher power (SNR) will generally have a significant advantage over a potentially better system operating at lower power. Different levels of distortion or noise in the electronics can also tilt the playing field.

To get around this problem, the Space and Naval Warfare Systems Center, San Diego, developed a set of versatile Telesonar Testbeds (Fig. 1). These are high fidelity, autonomous systems that transmit and receive a pre-programmed sequence of waveforms over an extended time period (several days). For the

sea tests, we assemble a variety of modulation schemes developed in-house or provided by external participants. We also transmit a sequence of channel probes to characterize the acoustic channel while measuring environmental conditions.
Currently, the internally fielded schemes are a 'research type-a', a type-x, and a PPM system. The type-a signaling scheme is a simple FSK approach with several channel-coding options and is virtually identical to the Benthos/Datasonics system. The type-x system is a classical DSSS (Direct-sequence, Spread-Spectrum) method using DPSK and a RAKE receiver not too different from the IS95 standard developed by Qualcomm. The code was originally developed by Northeastern University (Proakis and Sozer).

The principal focus for this year's work has been an experiment in the Pacific Missile Range Facility at Kauai. This experiment was conducted in parallel with HFX (High-Frequency Channel Characterization Experiment), which provided significant assets in terms of environmental characterization and design of the channel characterization component of the work. As the environmental measurements are described separately in the 321OA report, we shall be brief here. However, the suite of sensors/measurements included an ADCP, a waverider buoy, 7 thermistor strings, a CT string (conductivity), a multi-beam echo sounder, sidescan sonar, seismic profiler, and grab sampler.

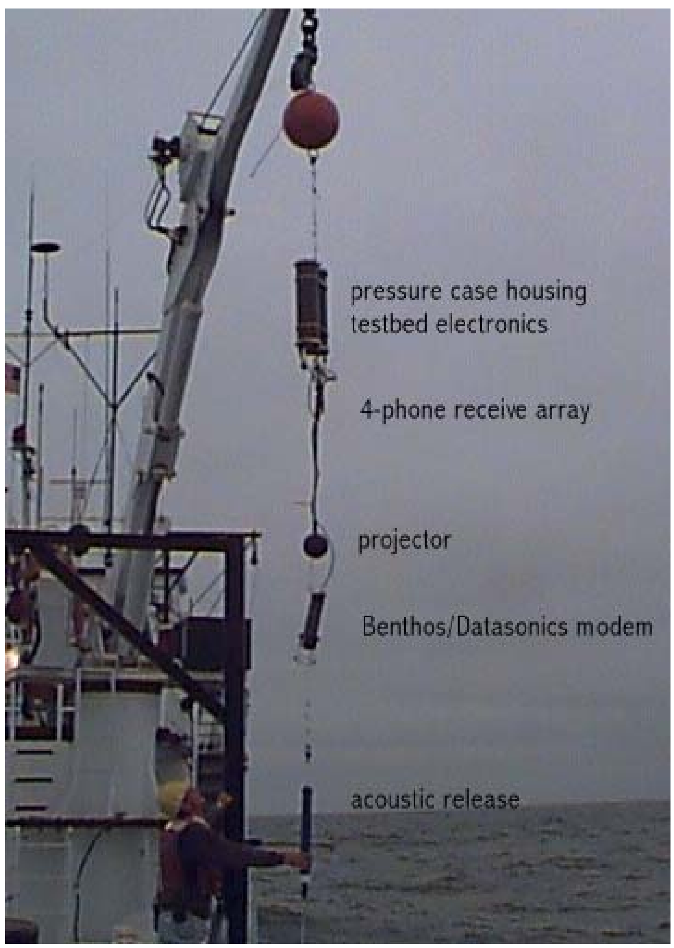

Fig. 1: Testbed configuration.

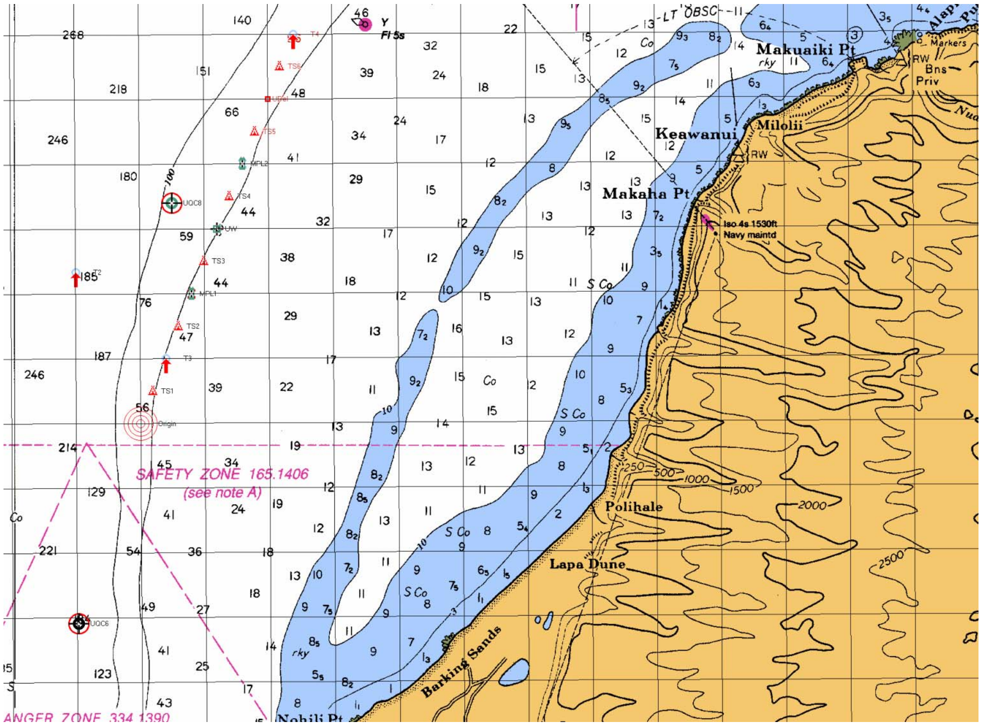

Figure 2: Experiment site at the Pacific Missile Range off Kauai.

In terms of the SignalEx modulation waveforms, the following techniques were tested: 1) research MFSK (similar to Benthos system); 2) DSSS (Direct Sequence Spread Spectrum), 3) OFDM (Orthogonal Frequency Division Multiplexing, 4) BPSK, QPSK, 8PSK; 5) FH-FSK (Frequency-Hopped Frequency-Shift Keying. Amongst these schemes, DSSS and FH-FSK are designed for multi-access (several users communicating at the same time). A deployment phase was included to specifically test this multi-access capability.

WORK COMPLETED

Much of this year's work has focused on planning and conducting the Kauai Experiment, which took place 22-June to 9 July. Since the data was only recently conducted, the data analysis is on going. However, thanks in large part to good weather, the experiment was essentially a complete success, yielding over 2 terabytes of data.

In preparation for this experiment, a large number of upgrades were made to the "telesonar testbeds" or T2's used to collect the acoustic data. By the time of the Kauai Experiment, 4 T2's were built and deployed, with temperature-compensated precision clocks (accurate to 1 min/year); remote command and control via a Benthos modem as well as RF control for on-deck programming and check out; and 3 frequency bands (8-16, 14-22, and 25-50 kHz). These new testbeds represent a major upgrade in capability and they performed flawlessly during the test.

Besides the testbeds, vertical line arrays from the Scripps Institution of Oceanography/ Marine Physical Laboratory, University of Washington/Applied Physics Laboratory and the University of

Delaware were also deployed. Three, full-deployment cycles were conducted, each one lasting roughly 48 hours, thus enabling us to sample both the short-time variability and the longer-term (diurnal) variability.

RESULTS

We will discuss here results from the "Research MFSK" scheme, which is extremely similar to that used in an acoustic modem commercially available from Benthos. The MFSK scheme is one of the simplest and may be compared to playing a pattern of chords on a piano. Each chord is used to encode a bit stream. Higher data rates are obtained by playing the 'music' more rapidly; however, the decoding of the chords becomes confusing if a new chord is played before the echoes of the previous one have died down. Results here are presented with the convolutional coder not applied. Convolutional coding greatly reduces the bit-error rates. However, it makes it harder for us to achieve our research goal of relating the environment to modem performance by increasing the required number of transmissions.

Figure 3 shows the Bit-Error Rates (BER) as a function of SNR and data rate. As discussed above, the higher data rates are obtained by using shorter tone-durations. With a shorter tone-duration, the detection of the tones is more easily confused by multipath spread, i.e. the surface and bottom echoes.

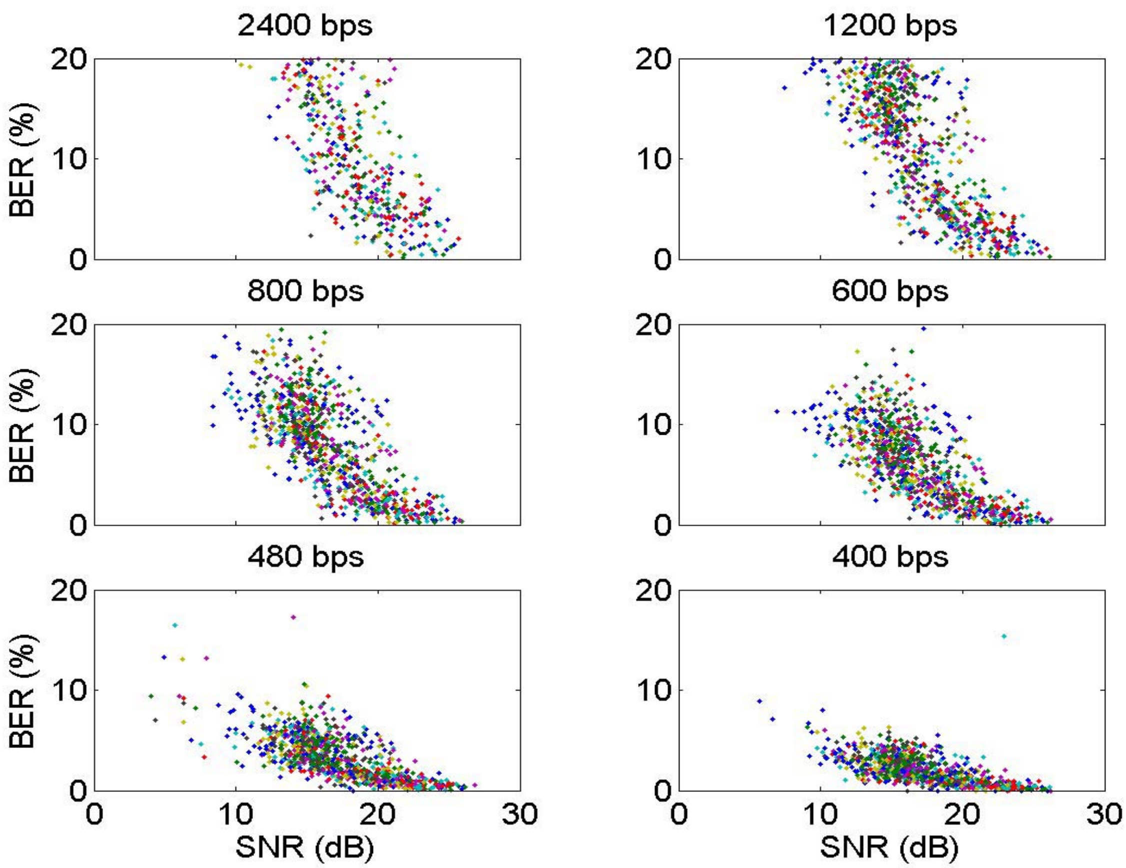

Figure 3: Bit-Error Rates as a function of SNR and data rate.

The role of multipath spread is highlighted in Figure 4. Here we show the change in BER over the course of a 1-day deployment. Periods with high BER are associated with times when the multipath spread was increased.

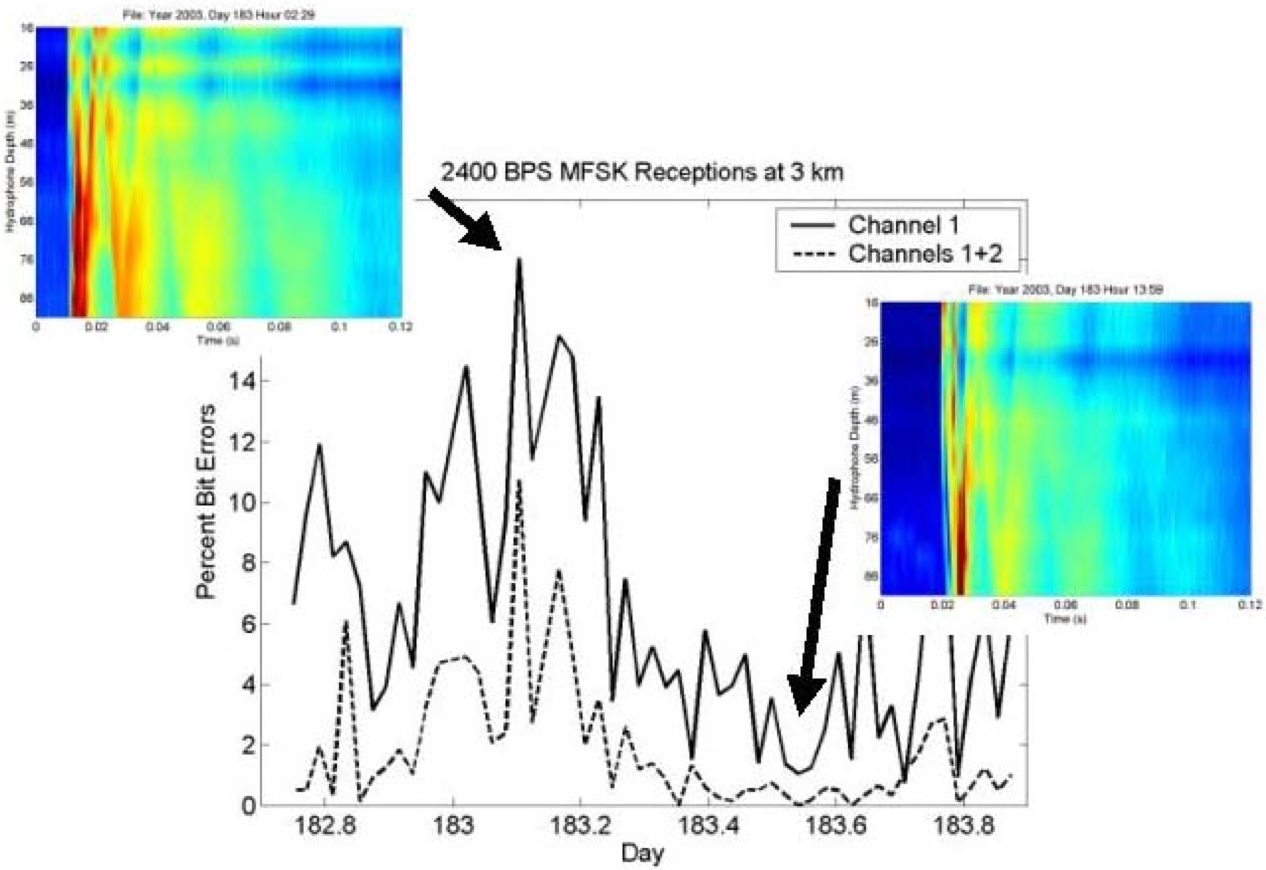

Figure 4: Bit-Error Rates are also highly sensitive to multipath spread, which in turn varies with time of day. Periods with high BER (inset on the left) are often associated with the longest multipath spread.

Figure 5 provides another indicator of the role of the environment. Here we have processed the acoustic receptions on one of the MPL VLA's, which spans most of the water column. As a result, we can see the strong variation in modem performance as a function of receiver depth.

On a qualitative level, these results give a sense of the variation of the modem performance as a function of environmental conditions. Undoubtedly, specific rules of thumb could be developed for particular modem schemes in restricted geographic areas. For instance, SignalEx tests to date suggest that very shallow water environments (about 10 m) are extremely favorable for modem performance, at least for the non-coherent modulation schemes we have tested. However, our interest is to be able to predict performance for diverse modem schemes including radically new ones being proposed.

Similarly, we would like to do so in very diverse environments with different water depths, bottom types, oceanographic conditions. As such, we have adapted the BELLHOP Gaussian beam tracing code as a channel simulator for arbitrary acoustic modulation schemes. The next step in this process is to run the transmitted waveforms through a channel simulator and verify that our simulator can reproduce the same trends that are seen in the data.

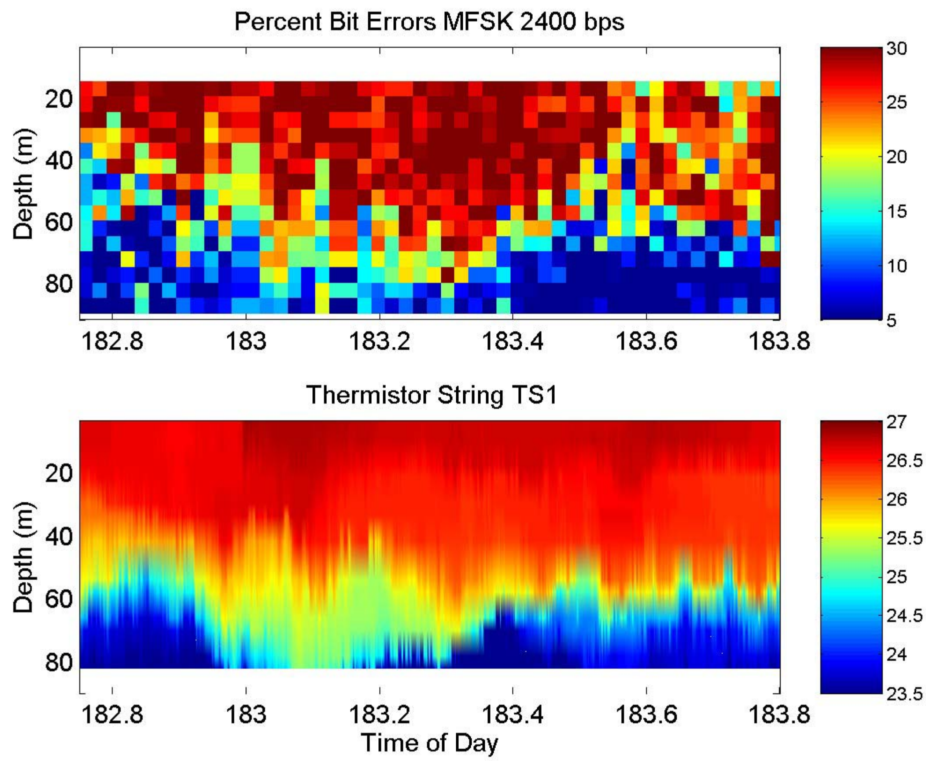

Figure 5: The role of the ocean environment is clearly indicated in this figure. The upper panel shows the Bit-Error rate for receivers at various depths in the water column and over a 1-day period. The lower panel shows the evolution of the ocean thermal structure over that same period. Note that receivers near the bottom show dramatically improved performance relative to receivers near the surface.

IMPACT/APPLICATIONS

Just as cellular phones have greatly enhanced our personal freedom, wireless underwater systems provide tremendous flexibility in connecting to underwater systems, including ocean measurement systems such as CTD's and ADCP's; AUV's; and autonomous surveillance arrays. Wireless systems based on 802.11b and Bluetooth are currently emerging as the physical layer of the terrestrial Internet; similar systems based on acoustic technology will likewise form the backbone of the oceanic Internet. Rapid and reliable signaling schemes will obviously be critical. Furthermore, being able to predict system performance in new deployment areas (or optimally select deployment sites) requires these careful SignalEx studies.

RELATED PROJECTS

SignalEx work this year was conducted in parallel with the High-Frequency Channel Characterization Experiment supported by ONR 321OA. Ongoing work will be conducted in close coordination with the High-Frequency Initiative supported by ONR321OA. Data from the SignalEx tests is also being analyzed for model-based tracking with partial support from ONR321SS.

PUBLICATIONS

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